ICMF'2001 — 4th Int. Conference on Multiphase Flow,
New Orleans, Louisiana, U.S.A.
May 27 – June 1, 2001

Experimental and Numerical Investigation of Particle Erosion Caused by Pulverized Fuel Flow in Channels and Pipework of Coal–Fired Power Plant

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The paper will be presented on the ICMF conference in New Orleans by Dr. Th. Frank.

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Keywords :

gas–particle flow, particle erosion, particle–wall interaction/collision, Eulerian–Lagrangian approach, numerical simulation of disperse multiphase flows

Abstract

In power plants using large utility coal–fired boilers for generation of electricity the coal is pulverized in coal mills and then it has to be pneumatically transported and distributed to a larger number of burners (e.g. 30–40) circumferentially arranged in several rows around the burning chamber of the boiler. Besides the large pipework flow splitting devices are necessary for distribution of an equal amount of pulverized fuel (PF) to each of the burners. So called trifurcators (without inner fittings or guiding vanes) and "riffle" type bifurcators are commonly used to split the gas–coal particle flow into two or three pipes/channels with an equal amount of PF mass flow rate in each outflow cross section of the flow splitting device.

These PF flow splitting devices are subject of a number of problems. First of all an uneven distribution of PF over the burners of a large utility boiler leads to operational and maintanance problems, increased level of unburned carbon and higher rates of NO_x emissions. Otherwise the bended pipework leading from the coal mills to the flow splitters and further to the burners results in an unequal concentration distribution over the cross section of the pipes (particle roping). This causes maldistribution of fuel between burners in the flow splitter and further leads to plant maintanance problems due to an uneven wear of PF pipework as well as the flow splitters themselfes.

The present paper deals with an experimental investigation and the development of a computational model for the prediction of particle erosion caused by the PF flow through the trifurcator and bifurcator flow splitting devices. Because the behaviour of PF flow is considerably influenced by the partical–wall collision process, the numerical prediction requires detailed information about model parameters of the particle–wall collision model for the specific material combination. In order to determine the details of the impact of small PF particles with steel or ceramic wall material we have investigated the collision process experimentally.

A special particle–wall impact test facility has been constructed which uses an injector for particle acceleration and allows the investigation of PF particle impingement on a target material by use of inert gases like e.g. CO_2 or N_2 for particle pneumatic transport inside the test rig in order to avoid dust explosion hazards. Several combinations of particle and wall materials, particle collision velocities under different impact angles has been investigated. The data were compared to those obtained for the impact of glass spheres, where existing bouncing models are proofed to be valid.

Secondly erosion rates were obtained as a function of particle impact angle and velocity for the material combination of PF and pulverized fuel ash (PFA) with a steel target. The erosion rate depends on the energy exchange between the erodent particle and the impacted material surface which can be characterized by restitution coefficients. However it was already found by Grant et al. (1975) that the restitution ratio v_2/v_1 does not give sufficient information in regard to erosion. Therefore the restitution ratio was broken down into a normal velocity restitution ratio v_{N2}/v_{N1} and a tangential velocity restitution ratio v_{T2}/v_{T1}. Their results show that the normal component of velocity does not contribute significantly to ductile erosion. As a result of the experimental investigations the erosion rate has been expressed in terms of the restitution parameters. These data give the foundation for the numerical prediction of particle erosion in devices of complex geometry like e.g. in the investigated "riffle" type bifurcators.

Finally the results of experimental investigations of particle–wall collision and particle erosion processes has been incorporated into a 3–dimensional computational model (MISTRAL/PartFlow–3D) developed by Frank et al. The numerical model is based on the Eulerian–Lagrangian approach. After the flow field is obtained from the finite volume discretization flow model (colocated variable arrangement, SIMPLE kind, multigrid), a large number of particle trajectories are computed using a 3–dimensional Lagrangian approach. Based on predicted particle impingements, erosion rates together with other details of the gas–particle flow can be obtained from numerical simulations. Due to the large numerical effort of those 3–dimensional gas–particle flow calculations a fully parallelized version of the numerical approach has been developed. Numerical predictions has been carried out on a parallel workstation cluster with 12 AMD–Athlon processors.

The computational model has been applied to the PF flow through the "riffle" type bifurcator. A numerical mesh for the complex geometry of the bifurcator including the interior fittings and guiding vanes has been constructed using ICEM/CFD–Hexa. The final numerical mesh consists of about 4 million grid cells. Erosion patterns are predicted for the rope splitting riffles and guiding vanes of the bifurcator for a number of different flow conditions. The influence of different particle roping patterns on the erosional wear to different parts of the bifurcator has been investigated numerically.